## ATTACHMENT S5A3: POTENTIAL REMEDIAL TECHNOLOGY SUMMARY

## 1.0 POTENTIAL REMEDIAL TECHNOLOGIES

Boeing Plant 2 (Plant 2) Contaminants of Concern (COCs) for soil and groundwater are organized into 11 groups as described in Section 4 of Volume X. This was done to facilitate effective descriptions and depictions of current soil and groundwater conditions for groups of COCs that have similar properties and similar fate and transport mechanisms rather than describing current conditions for each of the individual COCs. The Federal Remediation Technologies Roundtable (FRTR) Treatment Technology Screening Matrix (2002; included with this attachment) also groups contaminants into classifications that are similar to but are not identical to the Plant 2 COC groups. Table S5A2 lists the Plant 2 COC groupings and individual COCs included in each grouping and indicates where they fit within the six applicable FRTR contaminant classifications.

As noted in Section 5 of Volume X, the first screening step was to prepare a list of all potentially applicable technologies for soil and groundwater remediation at Plant 2. The list was based on a comparison of Plant 2 COC groups for soil and groundwater with the potentially applicable treatment technologies that are summarized in the FRTR Treatment Technology Screening Matrix (Attachment S5A1). This matrix summarizes soil and groundwater remedial options by their general treatment technology type. Applicability for Plant 2 was determined by retaining those treatment technologies that were rated as average or above average in the FRTR matrix for one or more of the COC groupings specific to Plant 2.

General response actions are broad categories of remedial actions that can be combined to meet the corrective action objectives defined in Section 1.7 of Volume X. With the exception of "Corrective Action Not Required," each of these response actions represents a category of potential remedial technologies. The following general response actions are presented in this attachment:

- Corrective Action Not Required
- Monitoring and Monitored Natural Attenuation (MNA)
- Engineering controls
- Institutional controls
- Containment
- In situ treatment
    - Biological
    - Physical / Chemical
    - Thermal
- Ex situ treatment
    - Biological
    - Physical / Chemical
    - Thermal
- Excavation
- Disposal (on or off site)

A summary of general response actions and technologies retained for evaluation is presented in Section 5 of Volume X.

## 1.1 Corrective Action Not Required

Corrective Action Not Required indicates that there would be no additional remedial actions conducted on site to reduce the potential of exposure to soil or groundwater COCs that exceed the proposed Final Media Cleanup Levels (FMCLs). Areas containing groundwater with COCs at concentrations exceeding proposed FMCLs are sufficiently protective of human health and the environment as long as the groundwater with COC exceedances does not discharge to the waterway. This situation is applicable for COC exceedance areas in groundwater that are limited to the upland (not present at the Point of Compliance (POC), and are well delineated and stable or shrinking. Areas with COC exceedances meeting these criteria may not require additional corrective action; thus, "Corrective Action Not Required" is retained for further consideration.

## 1.2 Monitoring and Monitored Natural Attenuation

Groundwater monitoring will be a required component of any site remedy. Short-term performance monitoring ensures that potential risks to human health and the environment are controlled while a site remedy is being implemented. Long-term compliance monitoring for groundwater is performed to demonstrate the effectiveness of the remedy and ensures that the remedy continues to be protective of human health and the environment. Long-term monitoring for soil includes routine site inspections as necessary to determine maintenance needs (e.g., for fencing or paved areas). A monitoring plan is retained for further consideration and will be developed based on the selected remedy.

Monitored Natural Attenuation (MNA) refers to reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remedial objectives within a time frame that is reasonable compared to that offered by other more active methods. The 'natural attenuation processes' that are at work in such a remedial approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These in situ processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants (USEPA 1999).

Factors that may limit the applicability and effectiveness of MNA include the following:

- Natural attenuation is not applicable in areas where imminent site risks are present.
- The hydrologic and geochemical conditions may change over time, resulting in migration of previously stabilized contaminants.
- Some inorganics can be immobilized but not degraded.
- Institutional controls and long-term compliance monitoring will be required.
- Longer time frames may be required to achieve remedial objectives, compared to active remediation.
- Outreach efforts may be required to gain public acceptance.

## 1.3 Engineering Controls

Engineering controls are physical restrictions or structures designed to monitor and minimize exposure of COCs at the site. Engineered cleanups may involve ongoing operation and maintenance (O&M), short-term monitoring, evaluation, periodic repairs, and replacement of remedy components (i.e., buildings, pavement, and stormwater controls). Engineering controls are effective, easily implemented, and low in cost. Four engineering controls – site access restrictions, dust control, and surface water controls, and paving – are evaluated in the following paragraphs, to determine if they will be retained for further consideration.

### 1.3.1 Soil Engineering Controls

**Site Access Restrictions** – Access restrictions prevent access by unauthorized persons. Fencing and guarded entrances are the most common means of restricting access. Fencing provides a physical barrier to site access. Guarded entrance gates restrict access from unauthorized persons. Security patrols are sometimes included for high-risk areas, but are not warranted for this site. Fencing and guarded entrances are retained for further consideration.

**Dust Control** – Dust control consists of measures to prevent wind dispersion of soil affected by COCs. Water is the most common method of short-term dust control. For long-term dust control, vegetation is planted to hold the soil together and reduce wind velocity at the ground surface. Dust controls related to excavation are retained for further consideration.

**Surface Water Controls** – Surface water management involves controlling surface water run-on and runoff at a site. The purpose of these controls is to minimize erosion that can expose underlying impacted soil. These controls are used as short-term measures (e.g., during excavation), or as long-term measures (e.g., within paved areas). Surface water controls alone are not generally effective as a permanent remedy and are typically used with other remedial technologies. Surface water controls include the following:

- Grading to promote stormwater drainage, reduce infiltration through paved areas, minimize erosion, and prevent or minimize stormwater run-on.
- Stormwater drainage controls (berms, ditches, and swales). Ditches and swales are channels designed to collect stormwater and route it to a discharge point. They can be unlined or lined with gravel, concrete, synthetic membranes, or other materials to reduce erosion. Piping can be used to route collected stormwater to a discharge point. Retention basins can be used to decrease soil erosion by reducing flow velocities and trapping sediment.
- Vegetative cover to reduce soil erosion. Once established, vegetation requires little or no maintenance and is highly effective in controlling erosion. Vegetation increases evapotranspiration rates, which reduces infiltration of stormwater.

Surface water controls are proven technology, effective, easily implemented, and inexpensive. Surface water controls are retained for further consideration.

**Paving (asphalt/concrete)** – Paving is a proven method of providing reliable, long-term containment to prevent, or significantly reduce, the migration of contaminants in soils. Containment is used when contaminated soils cannot be excavated and removed because of potential hazards, unrealistic cost, or lack of adequate treatment technologies.

Paved areas minimize risk by preventing direct contact with hazardous substances in affected soil and off-site migration of constituents in surface water or airborne dust. A low-permeability pavement design is used to reduce the potential for constituent migration into groundwater by reducing infiltration of precipitation.

Paved areas provide containment by

- Serving as a physical barrier to prevent humans, animals, and vegetation from coming in contact with impacted materials;
- Preventing erosion of soil by surface water and wind and preventing off-site transport of COCs; and
- Reducing infiltration of surface water and decreasing the potential for transport of COCs in the soil to groundwater.

Paved areas can be designed to be compatible with many potential future site uses. Land use restrictions and other engineering and institutional controls are typically employed with paved areas to prevent future site activities that could impact the integrity of the paved area (e.g., excavation or support pilings for buildings). Long-term maintenance and monitoring are required to maintain the grade and integrity of the pavement. Routine maintenance to repair cracks, settling, and potholes will be required.

Containment does not require excavation of soils, and therefore reduces engineering design, permitting, and material handling costs. Containment treatments require routine inspections for settlement, ponding of liquids, erosion, and naturally occurring invasion by deep-rooted vegetation. Paving is readily implemented using standard design and construction techniques. This technology is relatively low cost and highly cost-effective (i.e., high incremental protection relative to remediation cost). Paving is retained for further consideration.

### 1.3.2 Groundwater Engineering Controls

Engineering controls are not applicable to Plant 2's groundwater.

## 1.4 Institutional Controls

Institutional controls are administrative and legal restrictions such as environmental covenants, orders, permits, and state registries intended to reduce the potential for human exposure to contamination by limiting land or resource use. Institutional controls may be used to supplement engineering controls and must be operated, monitored, and evaluated for as long as the risks are present.

### 1.4.1 Soil Institutional Controls

**Environmental Covenants (ECs)** – ECs restrict land use by limiting activities at the site that may result in the release of COCs that were contained as a part of the cleanup action. ECs are legally binding notices of land use restrictions that accompany the property deed and transfer to any subsequent property owner. ECs include a description of restrictions on future activities or development that would cause direct exposure to COCs or compromise the integrity of the remedy. ECs are retained for further consideration.

### 1.4.2 Groundwater Institutional Controls

**Groundwater Use Restrictions** – USEPA has stated that the highest beneficial use of groundwater at Plant 2 is discharge to surface water (the Duwamish Waterway). In addition, there are groundwater use restrictions in place, including deed restrictions, that prevent development of the aquifer at Plant 2 as a source for drinking water. In addition, natural groundwater conditions at Plant 2 make development of the underlying aquifer unlikely.

The following information supports the highest beneficial use designation as discharge to surface water for groundwater underlying Plant 2:

- Plant 2 groundwater does not serve as a current source of drinking water. In addition, there is an extremely low probability that the groundwater at Plant 2 could ever be used as a source of potable water because there are no known uses or allowed uses of shallow groundwater for drinking water purposes within the Duwamish Valley north of the turning basin (Washington Administrative Code [WAC] 173-340-720(2)(a)).
- Plant 2 groundwater contains naturally occurring background concentrations of inorganic constituents that make its use as a drinking water source not practicable. Under Washington State Department of Health (WDOH) rules, a potential drinking water source must meet maximum contaminant levels (MCLs) for both primary and secondary contaminants. Plant 2 groundwater extracted for potable uses would contain excess chloride, iron, manganese, and total dissolved solids (TDS)/electrical conductivity. Groundwater at the Electrical Manufacturing Facility (EMF) Site contains natural background concentrations of these inorganic constituents that make use of the groundwater as a drinking water source not practicable. WDOH is required to enforce secondary MCLs when approving new water sources (Chapter 246-290 WAC) and considers the quality of the source water before treatment.
- Plant 2 groundwater is not a reasonable potential source of future drinking water given the industrial nature of the site and surrounding land use. Plant 2 will likely remain dedicated for industrial uses, and there are no areas where unpermitted residential wells could be installed.
- Additionally, the aquifer at Plant 2 is hydraulically connected to the Duwamish Waterway, which is a brackish to saline surface water body that is not suitable as a domestic water supply (tidally influenced by salt water) (WAC 173-340-720(2)(b)).
- Conditions under sections WAC 173-340-720 (2)(d)(ii),(iii) and (iv) are met. First, there are known and projected points of entry of the groundwater into the surface water (e.g., the Duwamish Waterway). Secondly, the Duwamish Waterway is brackish to saline; therefore, it is not classified as a suitable domestic water supply source (WAC 173-201A-602). Finally, the groundwater is sufficiently hydraulically connected to the surface water and to other connate water that is brackish, that the groundwater is not practicable to use as a drinking water source.

Based on the existing groundwater conditions, reasonable future site uses (i.e., non-residential and continued industrial use, and existing state and local regulations that prohibit installation of groundwater supply wells, it is recommended that the highest beneficial use for the groundwater at Plant 2 should remain discharge to the adjacent surface water (a saline portion of the Duwamish estuary).

## 1.5 Containment Technologies

Containment technologies physically isolate or limit the movement of COCs at the site and include paving to contain soil; physical barriers (i.e., slurry walls and sheetpiles), and deep well injection to contain groundwater. Containment technologies are effective, easily implemented, and relatively low in cost. Three containment technologies – paving, physical barriers, and deep well injection – are evaluated in the following paragraphs to determine if they will be retained for further consideration.

### 1.5.1 Soil Containment Technologies

A discussion of paving as a method of soil containment is presented in Section 1.3.1 above.

### 1.5.2 Groundwater Containment Technologies

**Physical Barriers** – Subsurface barriers that contain groundwater include vertically excavated trenches or large-diameter boreholes filled with slurry; or steel or PVC sheetpile walls driven into an underlying low-permeability layer. If a slurry wall is used, the slurry, commonly a mixture of bentonite and water, hydraulically shores the trench to prevent collapse and retards groundwater flow due to its low permeability. There are several special considerations for physical barriers as noted in the following paragraphs.

Physical barriers prevent the movement (mobility) of contaminants but do not reduce contaminant toxicity or volume. The contaminants are still present in the environment and represent an ongoing potential threat unless they are destroyed, degraded, or removed by another remedial technology. Use of this technology does not guarantee complete containment; additional remedial technologies may be necessary in the future.

Physical barriers are generally more effective if the bottom of the barrier wall can be extended into an underlying low-permeability geologic layer so that contaminated groundwater does not flow under the wall. The great thickness of the aquifer at Plant 2 does not allow standard trench-emplaced physical barriers to be installed through the full thickness of the aquifer, and any containment wall installed at Plant 2 would likely be a hanging wall that is not tied in at the bottom.

Most of the physical barrier approaches involve a large amount of heavy construction so the technology is commonly limited to smaller areas of very high contaminant concentrations or contaminants that have no other viable remedial technology.

Slurry walls and sheetpiles have the potential to degrade or deteriorate over time. Soil-bentonite backfills are not able to withstand attack by strong acids, bases, salt solutions, and some organic chemicals. Steel sheetpiles are susceptible to corrosion, especially in acidic or saline groundwater. Groundwater at Plant 2 is saline at locations near the Duwamish Waterway and at depth throughout Plant 2. PVC sheetpiles are resistant to saline groundwater and most chemicals but they degrade over time and can become brittle, making them susceptible to damage by seismic activity, which is possible during the anticipated lifespan of this technology. Physical barriers are a proven remedial technology at Plant 2; however, three existing steel sheetpiles at Plant 2 already contain soil and groundwater that historically had the greatest contaminant concentrations. No other areas of Plant 2 have contaminant concentrations in groundwater that warrant this remedial technology; therefore, physical barriers are not retained for further consideration.

**Deep Well Injection** – Deep well injection is a liquid waste disposal technology. This technology uses deep injection wells to place treated or untreated liquid waste into deep aquifers where it will not cause environmental harm.

A special consideration for deep well injection is that this remedial technique requires an underground injection control (UIC) permit from the Washington State Department of Ecology (Ecology). Ecology will not allow injection of contaminated groundwater into deeper underlying aquifers because this use would violate Ecology's non-endangerment performance standard for underground injection wells. Deep well injection is not retained for further consideration.

## 1.6 In Situ Treatment Technologies

The purpose of in situ treatment is to reduce the toxicity, mobility, or volume of COCs. The same treatment technologies that are available to treat ex situ soil are generally available to treat in situ soil. The primary advantage to in situ treatment is that soil is not excavated. The primary disadvantage is that the treatment process cannot be controlled as well as the same treatment in a reactor or other process equipment. This decreased control results from the difficulty in achieving desired process conditions and the inherent heterogeneity of the subsurface soil.

This section considers in situ soil treatment technologies including 1) physical/chemical, 2) biological, and 3) thermal technologies. In situ treatment processes are generally less effective at achieving treatment objectives and less reliable in achieving uniform treatment than the corresponding ex situ treatment process.

### 1.6.1 In-Situ Biological Soil Treatment Technologies

**Bioventing** – Bioventing techniques deliver oxygen to contaminated unsaturated soils by forced air movement (by extraction or injection of air) to increase oxygen concentrations and stimulate aerobic biodegradation. Bioventing has been successfully used to remediate soils contaminated by petroleum hydrocarbons, nonchlorinated solvents, some pesticides, wood preservatives, and other organic chemicals.

Bioventing stimulates the natural in situ biodegradation of any aerobically degradable compounds in soil by providing oxygen to existing soil microorganisms. In contrast to soil vapor vacuum extraction, bioventing uses low air flow rates to provide only enough oxygen to sustain and enhance microbial populations and activity. Oxygen is most commonly supplied through direct air injection into residual contamination in soil. In addition to degradation of adsorbed fuel residuals, volatile compounds are biodegraded as vapors move slowly through biologically active soil.

Bioventing is generally used at sites with mid-weight petroleum products (e.g., diesel fuel and jet fuel). Lighter petroleum products (e.g., gasoline) volatilize readily and can be removed faster using soil vapor extraction (SVE). Heavier petroleum products (e.g., lubricating oils) take longer to biodegrade than the lighter products.

Special considerations must be taken for sites with a groundwater table less than 10 feet below ground surface (bgs) because groundwater upwelling can occur within wells under vacuum pressures, potentially obstructing screens and reducing soil vapor flow. The ability of a soil to transmit air is reduced by the presence of water in the soil pores, which can block or reduce air flow. This is especially important in fine-grained soils, which tend to retain water.

Factors that may limit the applicability and effectiveness of bioventing include the following:

- High constituent concentrations may initially be toxic to microorganisms.
- Cleanup levels cannot always be achieved.
- Bioventing only treats unsaturated-zone soils. A high water table, saturated soil, or low-permeability soils reduce bioventing performance.
- Monitoring of off-gases at the soil surface may be required.
- Low temperatures may slow the remediation process.

Soil grain size and soil moisture significantly influence soil gas permeability. The greatest limitation to air permeability is excessive soil moisture. A combination of high water tables, high moisture, and fine-grained soils makes bioventing infeasible at some sites. Bioventing might require more time to achieve cleanup goals relative to SVE and is limited to specific soil permeabilities. This technology effectively treats volatile organic compounds (VOCs) in soil at a relatively low cost and is retained for further consideration.

### 1.6.2 In Situ Biological Groundwater Treatment Technologies

**Enhanced Reductive Dechlorination (ERD)** – ERD is also called Co-Metabolic Treatment; it is performed by injection of a dilute solution of nutrients dissolved in potable water and/or gases (e.g., methane or propane) into the contaminated aquifer to create or enhance geochemically reducing conditions and increase the rate of methanotrophic biological degradation of halogenated organic contaminants.

Special considerations must be taken for this technology. The strongly reducing geochemical conditions achieved by ERD can potentially increase the solubility of some metals, such as arsenic and manganese; however, this is a transient condition. The subsurface will return to pre-ERD geochemical conditions over time and with distance downgradient of the treatment area. However, if ERD is implemented at locations close to the Duwamish Waterway, the area of temporarily increased metals solubility could extend to the POC or to the waterway and could result in the discharge of groundwater with increased concentrations of arsenic and manganese, potentially exceeding proposed FMCLs for those metals. ERD is retained for further evaluation.

**Enhanced Aerobic Degradation (EAD)** – EAD increases the rate at which microbes aerobically biodegrade organic contaminants by increasing the concentration of electron acceptors (commonly oxygen) in groundwater. Oxygen can be supplied as a gas or through the injection of various compounds, commonly peroxides, which release oxygen into the groundwater.

There is only one special consideration for EAD as a treatment technology: it should not be performed simultaneously at a location where ERD is being performed because the two technologies are not compatible. ERD drives the subsurface geochemistry toward being anaerobic and EAD drives the subsurface geochemistry toward being aerobic, so their concurrent use in the same area would be ineffective. EAD is retained for further evaluation.

**Monitored Natural Attenuation (MNA)** – In MNA, natural subsurface processes such as dilution, volatilization, biodegradation, adsorption, and chemical reactions with subsurface materials are allowed to reduce contaminant concentrations to acceptable levels. MNA is commonly combined with other remedial actions and includes routine monitoring of remedial progress.

MNA might be applicable for COC exceedance areas that have been demonstrated to be stable or shrinking. Plume stability is commonly demonstrated by modeling or evaluations of empirical data. MNA might be appropriate for some metals when natural processes cause a change in the valence state of the metal that results in decreased solubility, leading to immobilization. At Plant 2 more aerobic geochemical conditions are measured in groundwater near the Duwamish Waterway, likely due to increased oxygenation from tidal fluctuations. Some metals currently do not reach the POC and the waterway likely because the dissolved metals making up the exceedance areas become insoluble under the more aerobic geochemical conditions near the waterway. MNA is not appropriate for exceedance areas that are at or near the POC and is not needed for stable or shrinking exceedance areas inland of the POC. For these reasons MNA is not retained for further evaluation.

**Phytoremediation** – Phytoremediation is a set of processes that use plants to clean contamination, particularly organic substances, in shallow groundwater and surface water.

Current and planned future land use at Plant 2 is a special consideration that precludes the use of phytoremediation as a groundwater treatment technology. Plant 2 is currently paved and will remain paved in the foreseeable future, with the exception of habitat areas and stormwater swales along the shoreline. The extensive pavement will prevent the use of plants to remediate shallow groundwater at the scale necessary to make this a viable remedial technology. Phytoremediation is not retained for further evaluation.

### 1.6.3 In Situ Physical/Chemical Soil Treatment Technologies

**Chemical Oxidation/Reduction** – Chemical oxidation-reduction reactions can be used to reduce toxicity or to transform a substance to one more easily handled. Oxidizing or reducing reagents are added to cause or promote the desired reaction. For example, oxidizing agents can be used to destroy or detoxify organic compounds. In some cases chemical oxidation/reduction technologies can be used for inorganics to oxidize reduced metals species to their less soluble oxide or hydroxide forms. The technology can be used but might be less effective for nonhalogenated VOCs and semi-volatile organic compounds (SVOCs), fuel hydrocarbons, and pesticides.

Chemical oxidation/reduction of affected soil is an unproven technology that requires special consideration. Many factors impact the effectiveness of the chemical treatment of soils including moisture content, soil porosity, pH, buffering capacity of the soil with the reagent used, and temperature. The balance of these and other factors determines the effectiveness of chemical treatment and can be difficult to control.

This technology is not effective for nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides. This technology is not retained for further consideration because of physical constraints and difficultly in verifying treatment effectiveness.

**Soil Vapor Extraction** – SVE is used for unsaturated (vadose) zone soil. A vacuum is applied to the soil through extraction wells to induce the controlled flow of air and remove VOCs and some SVOCs and fuels from the soil. The gas leaving the soil might require treatment to remove or destroy the contaminants depending on local and state air discharge regulations. Vertical extraction vents are typically used at depths of 5 feet or greater and have been successfully applied as deep as 300 feet. Horizontal extraction vents (installed in trenches or horizontal borings) can be used as warranted by contaminant zone geometry, drill rig access, or other site-specific factors.

Geomembrane covers can be placed over the soil surface to prevent short circuiting and to increase the radius of influence of the SVE wells. Groundwater depression pumps may be used to reduce groundwater upwelling induced by the vacuum or to increase the depth of the vadose zone. Air injection is effective for facilitating extraction of deep contamination, contamination in low-permeability soils, and contamination in the saturated zone.

SVE is generally more successful when applied to chlorinated and non-chlorinated VOCs and the lighter (more volatile) petroleum products such as gasoline. Diesel fuel, heating oils, kerosene, and lubricating oils are not readily removed by SVE.

Special considerations must be taken for sites with a groundwater table located less than 10 feet bgs because groundwater upwelling can occur. The permeability of the soil affects the rate of air and vapor movement through the soil; the higher the permeability of the soil, the faster the movement and the more vapors that can be extracted.

Factors that may limit the applicability and effectiveness of SVE include the following:

- Soil moisture content, organic content, and air permeability may limit the use of SVE.
- Concentration reductions of greater than about 90 percent are difficult to achieve.
- Effectiveness is less certain when applied to sites with low-permeability soil or stratified soils.
- SVE may require costly treatment for discharge of extracted vapors.
- Air emission permits are generally required.
- SVE only treats unsaturated-zone soils.
- Soil with a high percentage of fines and a high degree of saturation requires higher vacuums.
- Residual liquids may require treatment and disposal. Spent activated carbon used in the system will require regeneration or disposal.

This technology will not remove heavy oils, metals, polychlorinated biphenyls (PCBs), or dioxins. However, US Environmental Protection Agency (USEPA) performance data indicate that this technology effectively treats waste in place at a relatively low cost. This technology is retained for further consideration.

**Solidification** – Solidification involves mixing impacted soil with binding agents to form a solid matrix that immobilizes the COCs, and reduces constituent mobility (leachability). Solidification typically uses pozzolanic agents, such as cement, fly ash, and lime. This technology is effective for soil containing metals with concentrations greater than toxicity characteristic leaching procedure (TCLP) limits; it is generally not effective for soil containing VOCs and fuels. Factors that may limit the applicability and effectiveness of in situ solidification include the following:

- The depth of contaminants may limit these processes.
- Long-term monitoring is necessary to ensure that contaminants have not been re-mobilized.
- Soil characteristics (void volume, pore size, and permeability) influence whether the technology will contain the waste effectively. Void volume determines how much grout can be injected into the site. Soil pore size determines the size of the cement particles that can be injected. Permeability of the surrounding area determines whether water will flow around the solidified mass.
- This process is not cost-effective for small volumes of soil.
- This process cannot be conducted beneath buildings, other structures, or where existing underground utilities may prohibit the process.
- Some forms of this process result in a significant increase in volume (up to double the original volume).
- Certain wastes are incompatible with variations of this process. Treatability studies are generally required.
- Reagent delivery and effective mixing are more difficult than for ex situ applications.
- Confirmatory sampling can be more difficult than for ex situ treatments.
- The solidified material may limit future site use.

This technology is retained for possible use, but only to the extent to meet land disposal requirements prior to off-site disposal of metal COCs that exceed TCLP criteria.

### 1.6.4 In Situ Groundwater Physical/Chemical Treatment Technologies

**Air Sparging (AS)** – Air is injected into saturated matrices to remove contaminants through the physical process of volatilization. This technology is commonly combined with SVE, to remove the stripped volatile contaminants from the vadose zone. Depending on the contaminant type and concentrations, the vapor removed by the SVE system might require additional treatment (e.g., activated carbon, flare, or catalytic oxidizer) before discharge to the atmosphere.

There is a special consideration for this technology that must be considered for Plant 2. AS increases the dissolved oxygen content of groundwater within its area of influence, potentially creating aerobic geochemical conditions; AS is therefore incompatible with remedial strategies such as ERD that rely on reductive dechlorination. AS is retained for further consideration.

**Bioslurping** – Bioslurping combines the two remedial technologies of bioventing and vacuum-enhanced free-product recovery. Bioventing stimulates the aerobic bioremediation of contaminated soils in the vadose zone. Vacuum-enhanced free-product recovery of light nonaqueous phase liquids (LNAPL) extracts floating free product from the capillary fringe and the water table. Bioslurping does not directly address dissolved contamination.

There are no known areas of LNAPL in Plant 2 that would make the use of this free product recovery technique appropriate. Bioslurping is not an appropriate technology for remediation of dissolved contaminants in groundwater and is not retained for further consideration.

**Chemical Oxidation (ChemOx) –** ChemOx is the injection of an oxidizing agent such as sodium or potassium permanganate, hydrogen peroxide, or ozone into groundwater to destroy organic contaminants through chemical oxidation. Depending on site conditions, injections are generally performed along a transect running perpendicular to the groundwater flow direction or in a grid pattern within the contaminated area.

Chemical oxidation involves exothermic chemical reactions but this technology can generally be implemented in a manner that does not damage subsurface utilities and structures. However, the use of Fenton's reaction (iron-catalyzed hydrogen peroxide) can cause subsurface temperatures to increase to levels that potentially damage PVC piping, wire insulation, and other subsurface utilities. Because of this potential damage, ChemOx using Fenton's reaction will not be considered at locations near the duct bank or other sensitive subsurface utilities. Other less exothermic ChemOx technologies do not have this location limitation. ChemOx is also incompatible with ERD and should not be performed within exceedance areas that are actively undergoing ERD, although the two technologies can be performed sequentially. In addition, Plant 2 has naturally occurring anaerobic geochemistry and high concentrations of non-contaminant organics and reduced metals species, which would result in significant unproductive oxidant consumption. For these reasons ChemOx is not retained for further consideration.

**Directional Wells (not a stand-alone technology) –** Directional drilling techniques are used to position wells horizontally, or at an angle, to reach contaminants not accessible by direct vertical drilling. This is not a stand-alone remedial method but it can be used in conjunction with other in situ remedial methods to make them more effective.

All areas of groundwater exceedance that reach the POC are accessible to standard vertical drilling and probing techniques and directional drilling is not anticipated to be required at the site. Directional wells are not retained for further consideration.

**Dual Phase Extraction** – A high vacuum system is applied to simultaneously remove various combinations of contaminated groundwater, separate-phase floating product, and contaminant vapors from the subsurface.

There are no known areas of LNAPL that reach the POC in Plant 2 that would make the use of this free product recovery technique appropriate. Dual phase extraction is not an appropriate technology for remediation of dissolved contaminants in groundwater and is not retained for further consideration.

**Hydrofracturing Enhancements (not a stand-alone technology)** – Hydrofracturing injects pressurized water through wells to open cracks in low-permeability and over-consolidated sediments, creating increased secondary permeability. The cracks are held open with porous media (generally sand) injected as a slurry; this provides avenues for injection of remediation products and can improve groundwater pumping efficiency.

At Plant 2 there are no low-permeability or over-consolidated formations that potentially require hydrofracturing to allow injection of remediation products or to enhance the efficiency of groundwater pumping. The aquifer is amenable to injection of remediation products and groundwater extraction without hydrofracturing enhancements. Hydrofracturing enhancements are not retained for further consideration.

**In-Well Air Stripping, also known as Density Driven Convection (DDC)** – Air is injected into a double-screened well, airlift pumping water in the well and forcing it out the upper screen into an infiltration gallery. Simultaneously, additional groundwater is drawn in the lower screen. Once in the well, some of the VOCs in the contaminated groundwater are transferred from the dissolved phase to the vapor phase by air bubbles. The contaminated air in the well rises to the water surface where vapors are drawn off and treated by an SVE system. Additional VOCs are stripped from the groundwater as it passes through granular backfill in the infiltration gallery before infiltrating back into the aquifer.

Although DDC is mainly a physical removal remedial technology, the DDC process aerates treated groundwater, which causes aerobic geochemical conditions. This makes DDC incompatible with ERD, although the technologies may be used sequentially. DDC was effective as an interim measure at the 2-66 Sheetpile but cVOC concentrations that make this technology applicable are no longer present in groundwater at Plant 2. For these reasons, in-well air stripping / DDC is not retained for further consideration.

**Permeable Reactive Barriers (PRBs) –** PRBs allow the passage of groundwater while reducing contaminant concentrations by employing remediation agents such as chelators (ligands selected for their specificity for a given metal), sorbents, microbes, zero valent iron, and others. PRBs are applicable for many of the contaminants in Plant 2; however, the lack of a near-surface aquitard or low-permeability layer to key the bottom of the PRB into might limit the potential effectiveness of this technology.

PRBs are generally more effective if the bottom of the barrier wall can be extended into an underlying low-permeability layer so that contaminated groundwater does not flow under the PRB. The great thickness of the aquifer at Plant 2 does not allow standard trench-emplaced PRBs to be installed through the full thickness of the aquifer, and any PRB would likely be a hanging PRB that is not tied in at the bottom. This limitation can be partially mitigated by engineering design to ensure that the PRB is significantly more permeable to groundwater flow than the surrounding aquifer material. For these reasons PRBs are not retained for further consideration.

### 1.6.5 In Situ Thermal Soil Treatment Technologies

A description of thermal treatments is included in Section 1.7.5 of this attachment. In situ thermal treatment is generally more difficult to implement technically and administratively because of space limitations, stack testing, air permitting requirements, and public resistance. In situ thermal treatment for soil is not retained for further consideration.

### 1.6.6 In Situ Groundwater Thermal Treatment Technologies

In thermal treatments, steam or hot water is forced into an aquifer through injection wells or the aquifer is heated through electrical resistance to vaporize volatile and semivolatile contaminants. Vaporized components rise to the unsaturated zone where they are removed by vacuum extraction and are then treated as needed before the vapors are discharged to the atmosphere.

Thermal treatment requires hot water, steam, or electrical resistive heating, which is used to heat impacted soil and groundwater to temperatures that cause the contaminants to become more mobile and enter the vapor phase, where they are removed by SVE or similar technologies. The high subsurface temperatures generated by this technology could damage underground utilities or structures in treated areas. Because of the potential damage to sensitive subsurface utilities, thermal treatment will not be considered at locations near the duct bank or other sensitive utilities. For these reasons, thermal treatment for groundwater is not retained for further consideration.

## 1.7 Ex Situ Treatment Technologies

Ex situ treatment is intended to reduce the toxicity, mobility, or volume of material affected by COCs. Many ex situ treatment technologies convert COCs to less toxic forms. Destruction or degradation of organic compounds is possible (e.g., oxidation to carbon dioxide and water) although not always feasible or cost-effective.

The main advantage of ex situ treatment is that it generally requires shorter time periods than in situ treatment. Ex situ treatment is more uniform because of the ability to homogenize, screen, and continuously mix the soil. Ex situ treatment requires excavation of soils, which increases costs and engineering for equipment, permitting, and material handling and requires worker safety considerations.

This section considers a range of ex situ soil treatment following excavation including 1) physical/chemical, 2) biological, and 3) thermal technologies. If ex situ treatment of excavated contaminated material is selected as the recommended remedial alternative, a treatability study may be necessary to determine the appropriate treatment method.

### 1.7.1 Ex Situ Biological Soil Treatment Technologies

Bioremediation technologies are destruction or transformation techniques that stimulate microorganisms to grow by creating a favorable environment, using the contaminants as a food and energy source. Generally, this means providing some combination of oxygen and nutrients, and controlling the moisture, temperature, and pH. Biological treatment encompasses a number of treatment methodologies, can be performed ex situ and in situ, and may be accomplished by aerobic oxidation or anaerobic reduction processes.

Ex situ biological treatment technologies include biopiles, composting, landfarming, and slurry phase biological treatment. Bioremediation techniques have been successfully used to remediate soils, sludges, and sediment contaminated by light petroleum hydrocarbons, solvents, pesticides, wood preservatives, and other organic chemicals. It is not effective for soil contaminated with polycyclic aromatic hydrocarbons (PAHs), metals, and heavy oils. This technology is usually not suitable for solids wastes with high contaminant concentrations.

Contaminants can be destroyed or transformed, and little to no residual treatment is required. These processes require more time than other technologies and it is difficult to determine whether contaminants have been destroyed. The difficulty of implementation can vary widely, depending on the soil and COCs. Effective, biological treatment is usually inexpensive relative to other organic destruction technologies. Because of physical site constraints and lack of proven effectiveness in treating the organic COCs (motor-oil range petroleum hydrocarbons) at the site, ex situ biological treatment technologies for soil are not retained.

### 1.7.2 Ex Situ Biological Groundwater Treatment Technologies

**Bioreactors** – Contaminants in extracted groundwater are put into contact with microorganisms in attached or suspended growth biological reactors. In suspended systems, such as activated sludge, contaminated groundwater is circulated in an aeration basin. In attached systems, such as rotating biological contractors and trickling filters, microorganisms are established on an inert support matrix. Bioreactors require groundwater pumping and are most effective for conditions of high contaminant concentrations within a limited aerial extent. These conditions are not present at Plant 2, which significantly limits the applicability of this technology. For this reason bioreactors are not retained for further consideration.

**Constructed Wetlands** – Constructed wetlands treatment technology uses natural geochemical and biological processes inherent in an artificial wetland ecosystem to accumulate and remove metals and other contaminants, including organic compounds, from influent waters.

Current and planned future land use at Plant 2 precludes the use of constructed wetlands as a groundwater treatment technology. The site is currently paved and will remain paved in the foreseeable future, with the exception of habitat areas along the shoreline. The current and planned future land uses prevent the implementation of constructed wetlands at a large enough scale to effectively remediate groundwater at Plant 2. Constructed wetlands are not retained for further consideration.

### 1.7.3 Ex Situ Physical/Chemical Soil Treatment Technologies

Physical/chemical treatment uses the physical properties of the contaminants or the contaminated medium to destroy (i.e., chemically convert), separate, or immobilize the contamination. Soil washing, SVE, and solvent extraction are separation technologies, and chemical reduction/oxidation is a destruction technology. Solidification is an immobilization technology.

Physical/chemical treatment is typically cost-effective and can be completed in short time periods (compared with biological treatment). Equipment is readily available and the treatment technology is not engineering or energy intensive. Treatment residuals from separation techniques require treatment or disposal, adding to the total project costs, and may require permits.

**Reuse/Recycling** – Impacted soil can be reused and recycled as landfill cap material after being excavated and transported to a landfill. The reuse and recycling of impacted soils as landfill cover provides an effective permanent solution that is protective of human health and the environment and is easily implemented. This technology is retained because there are soils present on site with the potential for reuse or recycling primarily as landfill cap material.

**Dry Soil Sieving** – Dry soil sieving is an ex situ physical separation process performed without adding water. Soil is passed through one or more screens and separated into various size fractions to effectively concentrate contaminants into smaller volumes. This technology is based on organic and inorganic contaminants binding (physically or chemically) to the fine fraction of a soil. By separating the fine clay and silt particles from the coarser sand and gravel particles, the contaminants are effectively concentrated into a smaller volume of soil that can be treated or disposed.

Large-mesh screens (e.g., a grizzly) are commonly used to remove debris and other large objects from waste and affected soil. Although not as effective as physical soil washing, this technology is easy to implement and cost-effective because it generates a smaller volume of waste, reducing disposal costs. This technology is not retained for remediation at Plant 2 because site soils consist primarily of fine sands and silts, which are not suitable particle sizes for dry soil sieving.

**Physical Soil Washing** – The term "soil washing" is a water-based process for scrubbing soils ex situ to remove contaminants. “Physical soil washing” refers to soil washing for physical separation by concentrating contaminants into a smaller volume of soil through particle size separation and gravity separation. Physical soil washing is applicable in soils where the COCs are concentrated in a particular size soil fraction. In practice, the majority of COCs in soils are associated with the silt and clay soil fractions (collectively called the fines), with coarser soil (sand and gravel) being relatively clean. Soil washing systems are effective for soils contaminated with a wide variety of SVOCs, fuels, and heavy metals.

The effectiveness of physical soil washing is highly variable, depending on the COCs and site-specific conditions. Treatment of the wash water is necessary prior to discharge, and the fines must be dewatered before landfill disposal. Physical soil washing is a relatively complex process and requires use of specialized contractors. The limited solubility of petroleum products, particularly the heavier end oils, eliminates the use of water alone and requires the use of surfactants. Soil washing systems for site remediation are innovative and are currently in various stages of development and implementation. Physical soil washing would not provide proven, reliable treatment for this site, and would be difficult to implement based on site physical constraints and soil characteristics, primarily fine sands and silts. This technology is not retained for remediation at Plant 2.

**Chemical Extraction** – Chemical extraction refers to treatment processes using extracting chemicals to separate COCs from soils, sludges, and sediments by dissolving or suspending contaminants in the wash solution. The spent solvent or acid is then treated or recovered and recycled. Solvent extraction is effective in treating soils containing primarily organic contaminants such as PCBs, VOCs, halogenated solvents, and petroleum wastes. Acid extraction is effective in treating sediments, sludges, and soils contaminated by heavy metals.

The technology differs from physical soil washing, which generally uses water or water with wash-improving additives. Other solvents and reagents that can be used include surfactants, liquid carbon dioxide, and triethylamine (TEA) for organic compounds; petroleum solvents for oil recovery; and acids or complexing agents for metals.

A number of chemical extraction processes, including extractive soil washing, have been attempted at bench and pilot project scales with varying degrees of success. The effectiveness of chemical extraction is highly dependent on the COCs and site-specific waste characteristics. Published data show large variations in effectiveness between sites. Chemical extraction is not a proven, reliable treatment, is costly, and would be difficult to implement based on site physical constraints and soil characteristics, primarily fine sands and silts. This technology is not retained for further consideration.

**Chemical Oxidation/Reduction –** Chemical oxidation-reduction reactions can be used to reduce toxicity or to transform a substance to one more easily handled. Oxidizing or reducing reagents are added to cause or promote the desired reaction. For example, oxidizing agents can be used to destroy or detoxify organic compounds. Chemical oxidation/reduction technologies are used for inorganics. The technology can be used but may be less effective for nonhalogenated VOCs and SVOCs, fuel hydrocarbons, and pesticides.

Chemical oxidation/reduction of affected soil is an unproven technology. Many factors impact the effectiveness of the chemical treatment of soils including moisture content, soil porosity, pH, buffering capacity of the soil with the reagent used, and temperature. The balance of these and other factors determines the effectiveness of chemical treatment and can be difficult to control. This technology is not retained for further consideration.

**Solidification** – Solidification involves mixing impacted soil with binding agents to form a solid matrix that immobilizes the COCs, and reduces constituent mobility (leachability). Solidification typically uses pozzolanic agents, such as cement, fly ash, and lime. Selecting stabilization as a remedial technique requires laboratory testing to verify that the fixing agent is effective. The presence of high concentrations of adsorbed oil on soil particles being stabilized may interfere with the process and result in structurally poor soils. Proprietary additives are available that claim to improve immobilization and stability.

Solidification is an effective, established technology for treatment of wastes and soils affected by inorganic contaminants (e.g., heavy metals). Metals are typically immobilized by both chemical bonding and physical entrapment; organic compounds are immobilized only by entrapment.

The effectiveness of this binding agent with organic contaminants varies. Environmental conditions may affect the long-term immobilization of contaminants. Some processes result in a significant increase in volume (up to double the original volume). Treatability studies are generally required. Long-term effectiveness has not been demonstrated for many contaminant/process combinations.

Factors that may limit the applicability and effectiveness of ex situ solidification include the following:

- Soil characteristics (void volume, pore size, and permeability) influence whether the technology will contain the waste effectively.
    - Void volume determines how much grout can be injected into the site.
    - Soil pore size determines the size of the cement particles that can be injected.
    - Permeability of the surrounding area determines whether water will flow around the solidified mass.

- Some processes result in a significant increase in volume (up to double the original volume).
- VOCs are generally not immobilized.
- Long-term effectiveness has not been demonstrated for many contaminant combinations.

Solidification is a proven technology for immobilization of metals and PCBs, and can be implemented on site or off site. This technology is not retained, but may be used if needed to meet waste disposal requirements.

### 1.7.4 Ex Situ Physical/Chemical Groundwater Treatment Technologies (assumes pumping)

**Adsorption/Absorption –** In liquid adsorption, solutes concentrate at the surface of a sorbent, thereby reducing their concentration in the bulk liquid phase. Examples of adsorption/absorption technologies are activated alumina, forage sponge, lignin adsorption/sorptive clay, and synthetic resins.

There are some special considerations for adsorption/absorption. Some water-soluble compounds and small molecules, such as vinyl chloride, are not adsorbed well, which is a consideration for groundwater at Plant 2, which has areas of vinyl chloride contamination.

This technology is not applicable to sites having high levels of oily substances. Adsorption/absorption is not practical where the contaminant concentrations are so high that very frequent replacement of the adsorbent media is necessary as costs can be high if used as the primary treatment on waste streams with high contaminant concentrations; however, these limitation are not anticipated at Plant 2.

Spent adsorption media commonly require treatment/disposal as hazardous wastes if they can't be regenerated. Adsorption is a physical process with less than 100 percent efficiency. Therefore, this technology commonly requires several stages of media canisters to achieve target concentrations in the effluent, which increases capital and operational costs. This technology also requires groundwater pumping and is not efficient for low concentration exceedances over a large aerial extent, which is the case for most COPCs at Plant 2. For this reason, absorption is not retained for further consideration.

**Advanced Oxidation Processes/Ultraviolet (UV) Oxidation –** UV oxidation is a contaminant destruction process that oxidizes organic constituents in extracted groundwater by the addition of strong oxidizers and irradiation with UV light. Oxidation of target contaminants is caused by direct reaction with the oxidizers, UV photolysis, and through the synergistic action of UV light, commonly in combination with ozone and/or hydrogen peroxide. If complete mineralization is achieved, the final products of oxidation are carbon dioxide, water, and salts. The main advantage of UV oxidation is that it is a destruction process, as opposed to air stripping or carbon adsorption, for which contaminants are extracted and concentrated in a separate phase. UV oxidation processes can be configured in batch or continuous flow modes. In some cases off-gas treatment might be necessary to treat off-gases from the treatment tank or UV reactor.

For UV oxidation the aqueous stream being treated must provide for good transmission of UV light (high turbidity causes interference). Turbidity does not affect direct chemical oxidation of the contaminant by hydrogen peroxide or ozone (without UV) although the direct chemical oxidation treatments are less powerful.

Contaminated water containing free radical scavengers can inhibit contaminant destruction efficiency. In addition, the aqueous stream to be treated by UV oxidation should be relatively free of metal ions (less than 10 milligrams/liter [mg/L]) and insoluble oil or grease to minimize the potential for fouling of the quartz sleeves surrounding the UV lamps.

When UV or ozone is used on volatile organics such as trichloroethane (TCA), the contaminants may be volatilized (i.e., "stripped") rather than destroyed. They would then have to be removed from the off-gas by activated carbon adsorption or catalytic oxidation. Pretreatment of the aqueous stream may be required to minimize ongoing cleaning and maintenance of UV reactor and quartz sleeves. Handling and storage of oxidizers require special safety precautions. This technology requires groundwater pumping. More effective technologies exist for organics, and air stripping is not effective for inorganics, which significantly limits its potential use at Plant 2. For these reasons advanced oxidation processes / UV oxidation are not retained for further consideration.

**Air Stripping** – A physical contaminant removal technology in which volatile organics are partitioned from extracted groundwater by increasing the surface area of the contaminated water exposed to air. Aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration.

Air stripping is used to separate VOCs from water and is ineffective for non-volatile organic COCs and inorganic COCs. The Henry's law constant of a COC is used to determine whether air stripping will be effective. Generally, organic compounds with constants greater than 0.01 atmosphere ($m^3$/mol) are considered amenable to stripping. Compounds with low volatility at ambient temperature may require preheating of the groundwater to facilitate effective stripping. Off-gases may require treatment based on the mass emission rate of the stripped COC (FRTR 2002).

Pretreatment or periodic column cleaning is likely required if the water to be treated has high concentrations of inorganics (e.g., iron greater than 5 parts per million [ppm], hardness greater than 800 ppm) or if there is biological fouling of the equipment. Process energy costs are high. Air stripping is not retained for further consideration.

**Granular Activated Carbon (GAC)** – Groundwater is pumped through a series of canisters or columns containing GAC to which dissolved organic contaminants adsorb. Periodic replacement or regeneration of saturated GAC is required. GAC is a specific adsorptive media that is grouped and evaluated with adsorption/absorption. This technology requires groundwater pumping. More effective technologies exist for organics and GAC is not effective for many inorganics, which significantly limits its potential use at Plant 2. For this reason GAC is not retained for further consideration.

**Ion Exchange** – Ion exchange removes contaminant ions from the aqueous phase by exchange with innocuous non-contaminant ions on the exchange medium. Exchange media might consist of resins commonly made from inorganic, synthetic organic or natural polymeric materials that contain ionic functional groups to which the exchangeable ions are attached. After the capacity of the resin has been depleted it can be regenerated for re-use.

The exchange resin is susceptible to clogging if there are petroleum hydrocarbons in the groundwater. The performance of the ion exchange resin can also be adversely affected if the groundwater has a suspended solids content greater than 10 ppm. Wastewater is generated during the ion exchange resin regeneration step and likely requires additional treatment and disposal. In addition, this technology requires groundwater pumping and is not efficient for low concentration exceedances over a large aerial extent, which is the case for most COPCs at Plant 2. For these reasons, ion exchange is not retained for further consideration.

**Precipitation / Coagulation / Flocculation** – This process transforms dissolved contaminants into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process commonly uses pH adjustment by adding a chemical precipitant to convert dissolved contaminants to solids. The process is commonly enhanced by adding a chemical flocculent that causes the precipitant to aggregate to allow easier solid separation from the treated water. As with any pump and treat process, if the source of contamination is not removed, treatment of the groundwater may be ineffective.

The presence of multiple metal species may lead to removal difficulties as a result of amphoteric natures of different compounds (i.e., optimization on one metal species may prevent removal of another). Soluble hexavalent chromium requires extra treatment prior to coagulation and flocculation. Metals held in solution by complexing agents (e.g., cyanide or ethylenediaminetetraacetic acid [EDTA]) are difficult to precipitate.

This technology may present disposal issues, metal hydroxide sludges must pass TCLP prior to land disposal, and as discharge standards become more stringent, further treatment may be required for those sludges. In addition, treated water commonly requires pH adjustment prior to discharge. Polymer may need to be added to the water to achieve adequate settling of solids and the addition of reagents must be carefully controlled to preclude unacceptable concentrations in treatment effluent. Precipitation / coagulation / flocculation is retained for further consideration.

**Separation** – Separation techniques concentrate contaminated surface water or groundwater through physical and chemical means. Examples of separation technologies are distillation, filtration, freeze crystallization, membrane pervaporation, and reverse osmosis. Separation is mainly used as a pre-treatment or post-treatment process in a treatment train in combination with other treatment technologies. In addition, separation requires groundwater pumping. More effective technologies exist for organics and separation is not effective for many inorganics, which significantly limits its potential use at Plant 2. For these reasons, separation is not retained for further consideration.

**Sprinkler Irrigation** – Contaminated groundwater is distributed over the top of the filter bed through which groundwater is trickled. The microorganisms attached to the filter medium degrade organic contaminants in the groundwater.

This remedial technique releases stripped VOCs directly to the atmosphere, which is an unacceptable practice for the cVOC contaminants that, at Plant 2, are the target COCs for this remedial technology. Sprinkler irrigation is not retained for further consideration.

### 1.7.5 Ex situ Thermal Soil Treatment Technologies

Thermal processes use heat to separate (i.e., increase the volatility), destruct (e.g., burn, decompose, or detonate), or melt (i.e., immobilize) contaminants. Thermal treatment technologies are effective for destruction of organic COCs. Most thermal treatment technologies do not destroy or immobilize metals with the exception of vitrification, which can immobilize metals. Thermal treatment technologies offer quick cleanup times but are typically the most costly treatment group. Capital costs and O&M costs are high for energy and equipment.

Thermal separation technologies include thermal desorption and hot gas decontamination and produce an off-gas stream that requires treatment. Thermal desorption involves applying heat to waste in order to volatilize organic contaminants and water. Typically, a carrier gas or vacuum system transports the volatilized water and organics to a treatment system, such as a thermal oxidation or recovery unit.

**Incineration** – Incineration uses high temperatures to volatilize and combust organic constituents in hazardous waste. Incineration is typically used when chlorinated SVOCs are present with fuel; it is not typically used for soil contaminated by fuel alone. Incineration of halogenated compounds requires specific off-gas and scrubber water treatment to treat the halogen.

The destruction and removal efficiency (DRE) for properly operated incinerators exceeds the 99.99 percent requirement for hazardous waste and can be operated to meet the 99.9999 percent requirement for PCBs. Distinct incinerator designs are rotary kiln, liquid injection, fluidized bed, and infrared units. All types have been used successfully at full scale.

Factors that may limit the applicability and effectiveness of incineration include the following:

- Applicability and cost are affected by specific feed size and requirements for materials handling.
- Metals can produce a bottom ash that requires stabilization.
- Volatile metals, including lead, cadmium, mercury, and arsenic, leave the combustion unit with the flue gases and require the installation of gas cleaning systems for removal.

This technology is not retained, but may be used if needed to meet waste disposal requirements.

**Thermal Desorption** – Thermal desorption is an effective technology for destruction of organic compounds, with few limitations on the organic constituents of concern that can be treated successfully. The target contaminant groups for Low Temperature Thermal Desorption systems are nonhalogenated VOCs and fuels. This technology can be used to treat SVOCs at reduced effectiveness. The target contaminants for High Temperature Thermal Desorption are SVOCs, PAHs, and PCBs. VOCs and fuels may be treated, but treatment may be less cost-effective. Volatile metals (e.g., mercury) may vaporize during thermal treatment, requiring special treatment of the off gas. This technology is retained for possible use, but only to the extent required to meet land disposal requirements prior to off-site disposal.

Destruction technologies include incineration, open burn/open detonation, and pyrolysis. Destruction techniques typically have a solid residue (ash) and possibly a liquid residue (from the air pollution control equipment) that requires treatment or disposal. If the treatment is conducted on site, the ash may be suitable for use as clean fill. If the material is shipped off site for treatment, it may require pretreatment prior to landfill disposal.

Ex situ incineration and thermal desorption will be performed as required to meet land disposal restrictions for landfill disposal.

Factors that may limit the applicability and effectiveness of thermal desorption include the following:

- Applicability and cost are affected by specific particle size and requirements for materials handling.
- Dewatering may be necessary to achieve acceptable soil moisture content.
- Metals in the feed may produce a treated solid residue that requires stabilization.
- Binding contaminants in clay and silty soils increase reaction time.

Thermal desorption is technically and administratively achievable for Plant 2 and is not retained for further consideration, but may be used if needed to meet waste disposal requirements.

**Vitrification** – Vitrification converts a substance into a glass-like solid by using electric rods to raise the soil temperature to its melting point. As the soil cools, it forms a glass-like state, which is chemically inert and has low leaching characteristics. Vitrification technologies immobilize inorganics and destroy some organics. Vitrification processes drive off moisture and eliminate air spaces, which produces a decreased slag volume compared to untreated soil. The technology is expensive and can be limited by variations in soil composition, groundwater depth, and soil permeability. This technology is not retained for consideration.

## 1.8 Source Removal

### 1.8.1 Soil Excavation

Excavation is a general response action for soil affected by COCs prior to ex situ treatment or disposal (on site or off site). Excavation can be complete (i.e., all portions of soil with COC above remediation goals), or partial (i.e., the highest concentrations of a COC). Excavation alone is not a complete remedial alternative; it must be combined with treatment and/or disposal of the removed soil.

Excavation of affected soil from the contaminated areas is technically feasible. Equipment used for excavation includes backhoes, loaders, bulldozers, clamshells, and draglines. The choice of equipment is typically made by the excavation contractor.

Factors that may limit the applicability and effectiveness of the process include the following:

- Dust emissions are generated during excavation.
- Cost is affected by the distance from the contaminated site to the nearest disposal facility with the required permit.
- Depth to water table and soil composition can limit the depth and extent of excavation.
- Transportation of the soil through populated areas may affect community acceptability.
- Contaminants could migrate from excavated materials to surface water or leach into groundwater.

Excavation is retained for use with appropriate treatment or disposal technologies (ex situ treatment or off-site disposal).

### 1.8.2 Soil Excavation as a Groundwater Technology

Although soil excavation is a soil remedy it is also applicable to address groundwater impacts at locations where contaminated soil or fill material affects localized shallow (A-Level) groundwater. Removal of contaminated soil or fill material can be followed by further groundwater remedial technologies or by monitoring to evaluate if the source removal action was sufficient to achieve compliance with proposed FMCLs in groundwater.

Many of the groundwater remedial technologies presented in this attachment are not applicable or effective in areas containing free product or high contaminant concentrations. Removing contaminant source material by direct excavation of impacted soil increases the number of groundwater remedial technologies that can be effectively implemented and also likely shortens the time necessary to achieve proposed FMCLs at the POC.

Excavation and disposal of impacted soil is relatively easy for vadose-zone soil, but this source removal technology becomes significantly more difficult and costly for saturated soils, which could require dewatering, treatment, and disposal of the removed groundwater. At Plant 2 most of the soil with high COC concentrations is in the vadose zone so deeper excavations are not anticipated. Excavation is retained for further consideration.

## 1.9 Disposal (On- or Off-Site)

Disposal is a general response action for final disposition of excavated soil or waste generated by treatment processes. Landfill disposal relocates COCs from one place to another for long-term containment; it does not use treatment to destroy or detoxify COCs. If needed, treatment can be used prior to disposal. Disposal options following excavation include an on-site constructed landfill and an off-site landfill (including any required treatment to meet land disposal regulations).

**On-Site Disposal (Consolidation of Impacted Soil)** – On-site consolidation of impacted soil requires excavation of an area large enough to contain the contaminated soil, containment (i.e., liner), capping, and long-term monitoring. At Plant 2, physical constraints and existing paved areas limit the area available for on-site disposal. On-site disposal is not retained for further consideration.

**Off-Site Disposal** – Commercial or municipal landfills could be used for disposal of waste or affected soil excavated from contaminated areas. The disposal facility is determined based on waste characteristics, land disposal restrictions, and regulatory compliance requirements. Municipal landfills (Subtitle D) accept waste that is classified as non-hazardous under federal Resource Conservation and Recovery Act (RCRA) regulations or as non-dangerous under Washington State dangerous waste regulations.

Hazardous waste landfills (Subtitle C) accept listed or characteristic hazardous waste under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) regulations. Landfilling hazardous waste is technically feasible and cost-effective for sites with moderate volumes of soil, moderate depths, and simple hydrogeologic conditions. The cost of off-site disposal could be decreased if the waste is treated prior to disposal. Off-site disposal is retained for further consideration.

## 2.0 REFERENCES:

Federal Remediation Technology Roundtable (FRTR). 2002. Remediation Technologies Screening Matrix and Reference Guide, 4th Edition. Online: http://www.frtr.gov/matrix2/section3/table3_2.pdf (accessed March 2014).

U.S. Environmental Protection Agency (USEPA). 1999. OSWER Directive 9200.4-17P -- Use of monitored natural attenuation at Superfund, RCRA corrective action, and underground storage tank sites -- April 21, 1999: Office of Solid Waste and Emergency Response, 41 p.